

Spacings for Subsurface Drains in Heavy Soils

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G. O. SCHWAB, D. W. MICHENER, and D. E. KOPCAK²

INTRODUCTION

The design of subsurface drainage systems for a given rate of water table drawdown requires a knowledge of the hydraulic conductivity and drainage porosity of the soil. Field *in situ* methods and soil cores which involve point measurements to determine soil properties have not been practical because of the large variability between samples, requiring a large number of measurements. Even so, these methods have merit and are more theoretically sound than trial and error estimates based on field experience from which present spacing recommendations were developed.

Hoffman and Schwab (2) developed a procedure for measuring soil properties by measuring the water table drawdown and flow rate from an existing drain system following a wet condition. Skaggs (9) modified the procedure so that only drawdown rates were needed when evapotranspiration was minimal. His method is also applicable for a single drain and for either a rising or falling water table. Both methods require an installed drainage system several years old and high initial water table conditions. Field effective values of hydraulic conductivity and porosity are obtained. These are not the same as point values. Once known, hydraulic conductivity and porosity are then substituted into an appropriate equation to obtain spacings for boundary conditions other than those for the system from which measurements were made.

Skaggs' procedure and a computer model were used in this study. Outflow and drawdown were measured so that effective porosity and corrections for evapotranspiration could be computed. The major advantage of his method is that measurements are obtained from a large undisturbed area (volume of soil) compared to core or auger hole measurements. The data are applicable only for the measured site, but hopefully the results are representative of all soils of the same type.

Soils were selected because they were slowly permeable and were borderline with regard to subsurface drainage suitability. The soil type and acreage of these soils in Ohio are: Toledo—263,000 acres, Paulding—194,000, Hoytville—175,000, Clermont—149,000, Avonburg—133,000, Nappanee—100,000,

Latty—69,000, and Roselms—61,000. Paulding, Roselms, Clermont, and Latty soils are also found in small areas of Indiana and Michigan. At least 50 soils in the U. S. are similarly poorly drained and need to be evaluated.

OBJECTIVES

The general objective was to determine pipe drain spacing recommendations for selected heavy soils. Specific objectives were:

- To determine if pipe drains function adequately in selected slowly permeable soil types.
- To recommend pipe drain depth and spacings from field measurements for selected rates of water table drop and depth of water table.
- To evaluate soil layering and other soil properties, such as drainable porosity, that influence water table drawdown and thus spacing.

EQUIPMENT AND INSTRUMENTATION

A list of the equipment required for the field tests is given in Appendix A.

PROCEDURE

Field Studies

Field sites were selected to be representative of the soil series and to be within a few hundred meters of a local water supply for irrigation. Normal layout of sprinklers, drain lines, and water table pipe are shown in Figure 1. A pit was dug 0.75 m deeper than the test drain and about 10 m from the first sprinklers. Irrigation water was kept from the pit and the walls were braced to prevent cave-ins. A V-weir with chart recorder and a pump were installed in a plywood box set in the pit. Discharge from the pump was returned to the drain downstream from the test plot.

Three lines of water table pipe A, B, C were installed with a power auger to the depth of the drain. Pipes 2 and 8 on each line were at midspacings between the drains, 3 and 7 at the 0.25 spacing, and 4 and 6 at the 0.1 spacing from the test drain. Pipe 5 was directly over the drain. Pipes 1 and 9 (not shown in Fig. 1) were located 1.5 times the spacing from the test drain. Each pipe was packed in filter sand up to 15 cm from the surface and then with soil to 3 cm above the surface to prevent inflow of surface water. The pipes were flushed out and then filled with water near the end of the sprinkling time in or-

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TABLE 1.—Field Sites, Rainfall and Test Summary.

Soil Type	Av Drain Depth (m)	Av Drain Spacing (m)	Plot No.	Test No.	Test Date Start	Irri- gation Depth (mm)	Av Land Slope (%)	Land Cover or Crop*	Rainfall During 0-30 cm Drawdown (mm)
Toledo silty clay	0.97	12.2	1C, 3C	1	6/3/77	76	0	C&S	0
			1C, 3C	2	6/23/77	76			0
			1C, 3C	3	6/13/78	66			0
			1C, 3C	4	6/23/78	66			0
	0.46	3.0	1	1	9/8/77		0.5	M	0
				2	5/16/78				10
	0.47	9.1	2	1	9/8/77		0.5	M	0
				2	5/16/78				10
	0.46	12.2	4	1	9/8/77		0.5	M	0
				2	5/16/78				10
Roselms clay loam	1.09	10.1	1	1	11/4/77	51	0.8	B	0
				2	11/7/77	33			10
	1.13	10.1	2	1	11/4/77	51	0.7	B	0
				2	11/7/77	33			10
Paulding clay (1)	0.94	10.1	1	1	10/25/77	69	0.2	B	3
				2	11/1/77	†			3
	0.92	10.1	2	1	10/28/77	62	0.3	B	1
				2	11/1/77	†			2
Latty clay	0.73	13.1	1	1	11/18/77	46	0.1	Cl	0
				2	11/19/77	41			7
	0.94	11.1	2	1	11/21/77	53	0.1	Cl	0
				2	11/30/77	51			4
Clermont silt loam (Ohio)	1.12	14.6	1	1	4/13/78	69	0.3	B	0
				2	4/17/78	52			77
	0.98	15.0	2	1	4/13/78	69	0.3	B	0
				2	4/17/78	52			71
Avonburg silt loam	0.95	15.6	1	1	4/24/78	29	0.4	B	16
				2	4/27/78	27			2
	0.96	15.6	2	1	4/24/78	29	0.4	B	16
				2	4/27/78	27			2
Hoytville silty clay loam	1.03	12.2	1	1	10/29/78	129	0.5	B	0
				2	11/1/78	110			0
	1.08	12.2	2	1	10/29/78	129	0.5	B	0
				2	11/1/78	110			0
Clermont silt loam (Indiana)	1.00	15.2	1	1	11/17/78	113	0.4	B	0
				2	11/20/78	41			0
	1.09	15.2	2	1	4/15/79	51	0.5	B	0
				2	4/19/79	59			0
Paulding clay (2)	0.85	10.6	1	1	5/10/79	93	0.1	B	0
				2	5/15/79	57			0
	0.83	10.7	2	1	5/10/79	93	0.1	B	0
				2	5/15/79	57			0
Nappanee silty clay loam	0.86	12.3	1	1	6/1/79	54	0.4	W	0
				2	6/5/79	60			0
	0.91	12.2	2	1	6/1/79	54	0.5	W	0
				2	6/5/79	60			0

*C—corn, S—soybeans, M—meadow, B—bare, Cl—clover, W—wheat.

†Water table from rainfall of 10 mm.

der to equalize the water level in the pipe with that in the soil.

Each plot was irrigated about 7 to 13 hours with an application rate of about 7.5 mm/hr until the drain flow was nearly constant and the water table was close to the surface. The number of tests and plots are shown in Table 1 for each soil. Depth of water application was measured using an array of cans within a four-sprinkler area. Recording gages were installed for drain flow and rainfall. Point in time readings were taken for water table, pan evaporation, and water temperature. Water table read-

ings were taken hourly or more frequently for the first few hours after drawdown and then less frequently for 48 hours or longer. Specific times are shown on computer printout sheets.

Data Processing

The field data were placed on punch cards and processed on The Ohio State University computer. The general procedure is outlined in Table 2. Values for tau (τ) and mu (μ) presented by Skaggs (9) were utilized in the computations. The drainage porosity for each soil was computed from field data for the tile spacing program.

TABLE 2.—General Procedure for the Computer Program.

1. Read survey data: top of well, ground surface at well, probe length, top of probe, instrument elevation, tile diameter.
2. Calculate elevations: ground surface above tile line, top of well above tile line.
3. Read water table readings, evapotranspiration (ET), time, date, and tile flow.
4. Check for improper readings: blanks, dry wells, rising water table with rainfall.
5. Compute elapsed time, total and incremental ET, and tile flow.
6. Read values of depth to impermeable layer (d) and correction factors of ET for porosity calculations.



POROSITY PROGRAM

1. Calculate initial weighted drawdown of water table from soil surface.
2. At each time calculate incremental and total weighted drawdown of water table from initial level.
3. Compute total porosity (f) and incremental f for various ET correction factors.
4. Print total porosity and incremental f at each time for all ET correction factors.

TILE SPACING PROGRAM

1. Enter loop for design drawdown rates of 10, 20, 30 cm/day to 10, 20, 30 cm depths.
2. Compute variables for K/f calculations: y, y_0 , h_0 (all measured from initial water table readings), D, t, and X/L.
3. For each well, determine τ based on μ (ET), Y, X/L, and D. Calculate K/f from τ , h_0 , L and t.
4. Calculate average K/f for X/L = 0.1, 0.25 and 0.50.
5. Determine the spacing based on average K/f using $\mu = 0$ (no ET), and X/L = 0.50 for all three cases.
6. Calculate the average drop at midpoint for each time.
7. Continue for all times and design drawdowns.
8. Print time, average drop at midpoint, and the average spacings and K/f for X/L = 0.1, 0.25, and 0.50.

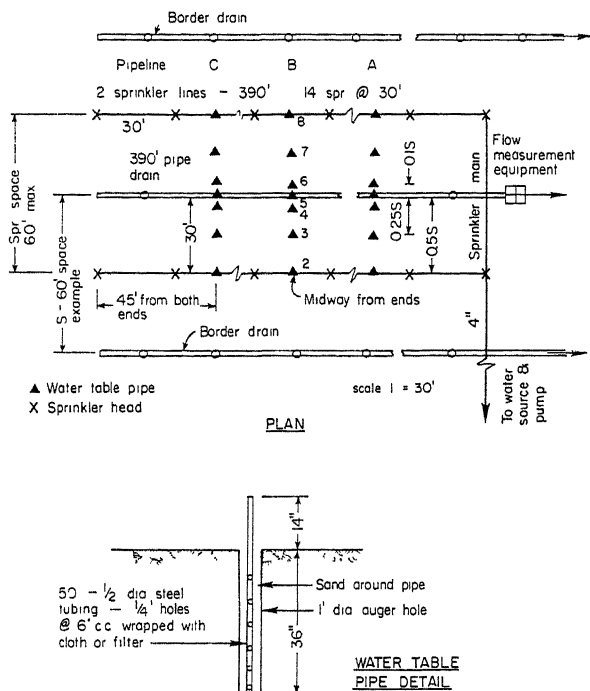


FIG. 1.—Layout of sprinkler irrigation system, drain lines, and water table pipe.

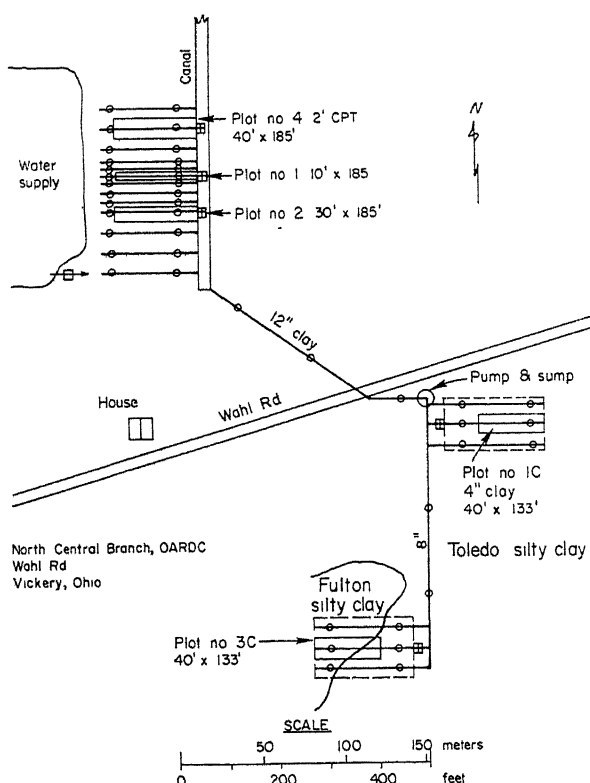


FIG. 2.—Toledo soil site.

FIELD SITES

In Table 1, average drain spacing, drain depth, irrigation depth, and land slope are shown for each soil type by plot number and test number. Rainfall during the test trial, land cover, and beginning test dates are also included. More detailed soil descriptions are in Appendix D. Maps of each site are shown in Figures 2, 3, 4, 5, 6, 7, 8, and 9.

Toledo Silty Clay (Mollic Haplaquept)

In 1976 through 1978, plots 1C and 3C were cropped to one-third corn, one-third soybeans, and one-third oats in rotation (see Fig. 2). These plots were bare from fall 1972 to fall 1973 and in alfalfa-timothy-meadow until fall 1975. In prior years all plots were land leveled. A 1.22-m plastic barrier was installed at the outside plot boundary and a 0.15-m high earth dike was placed around each plot. The pipe drains were installed in 1957. Only two-thirds of the plot, the corn and soybeans, were irrigated. The shallow drained plots 1, 2, and 4 were seeded to meadow in fall 1973. The pipe drains were installed in November 1971. At that time the plots were graded to 0.5% slope.

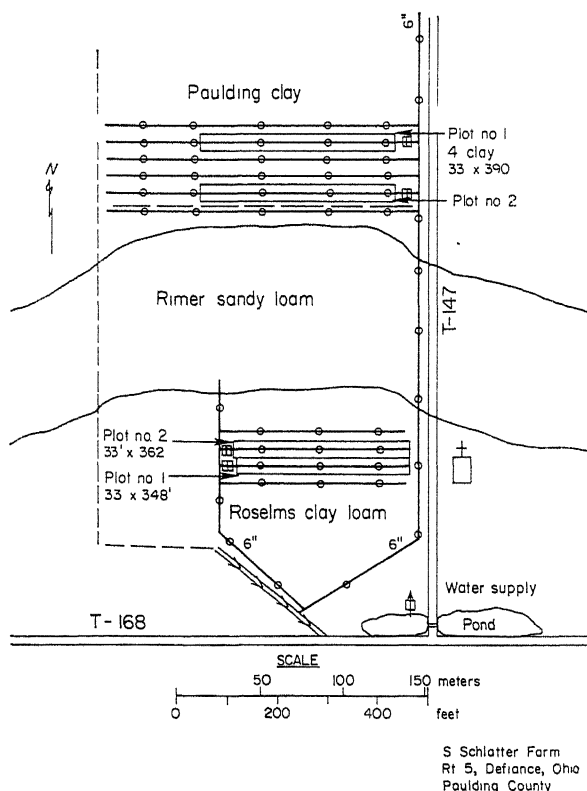


FIG. 3.—Paulding (1) and Roselms soil sites.

**Paulding Clay (1) (Typic Haplaquept)
and Roselms Clay Loam (Aeric Ochraqualf)**

The Paulding (1) and Roselms plots (Fig. 3) were cropped in a 4-year rotation of corn, wheat, soybeans, and meadow with meadow in 1977. When planted to row crops, land leveling and ridging were performed. Pipe drains were installed in 1963. When cropping, fall plowing was practiced, weather permitting. In August 1977 these plots were plowed and leveled prior to the test trials.

Latty Clay (Typic Haplaquept)

Plots 1 and 2 (Fig. 4) were in clover for more than 5 years and were previously land leveled. The drains on plot 1 were installed about 1947. In 1957 drains were installed in plot 2. All the drains outlet into an open ditch. The ditch was temporarily dammed for a source of irrigation water.

**Clermont Silt Loam (Ohio) (Typic Ochraqualf)
and Avonburg Silt Loam (Aeric Fragiaqualf)**

These plots (Fig. 5) were cropped to soybeans in 1977, wheat and soybeans in 1976, and soybeans 1972-75. During drain installation in August 1976, the trench was backfilled by augering topsoil into the trench and spreading the subsoil over the surface. Tillage in most years was chisel plow-disc-plant. Drain tests were made prior to tillage in 1978, at which time soybean residue remained and the soil surface was nearly smooth.

Hoytville Silty Clay Loam (Mollic Ochraqualf)

Pipe drains were installed in August 1960. Recent crop history includes soybeans in 1978, sugar beets in 1977, soybeans in 1976 and 1975, and corn in 1974. The field (Fig. 6) was fall plowed each

year when possible, followed by secondary tillage in the spring with a field cultivator as needed. The field was leveled in the fall of 1977. At the time of testing the soil surface was soybean stubble.

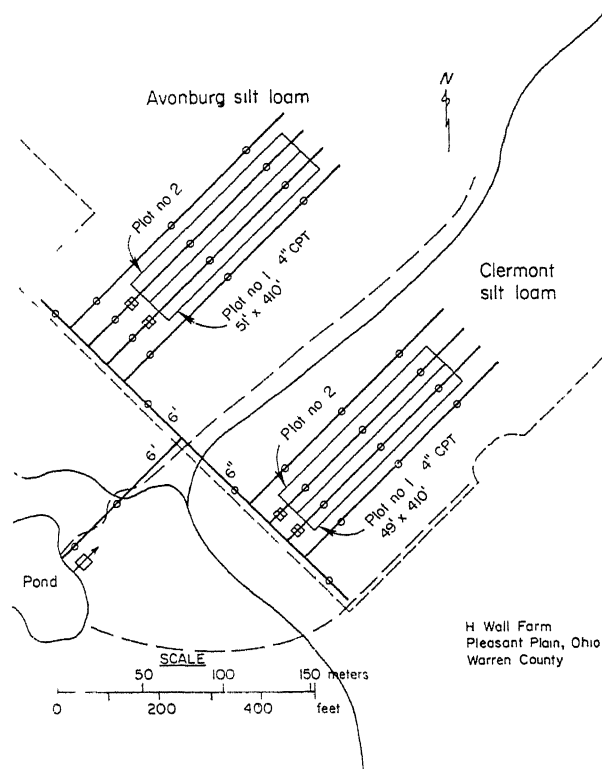


FIG. 5.—Clermont (Ohio) and Avonburg soil sites.

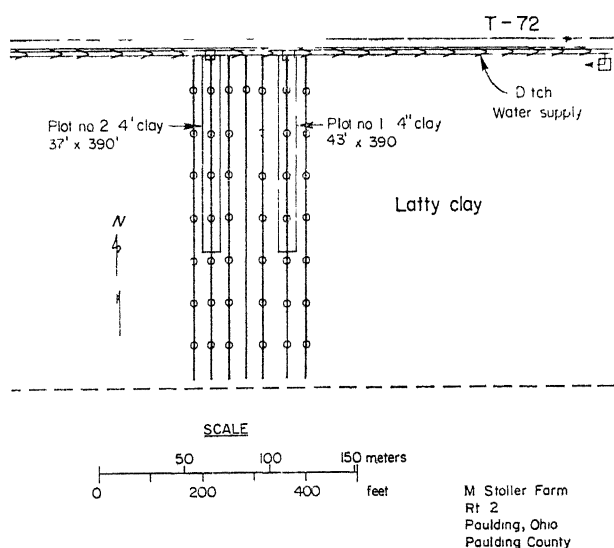


FIG. 4.—Latty soil site.

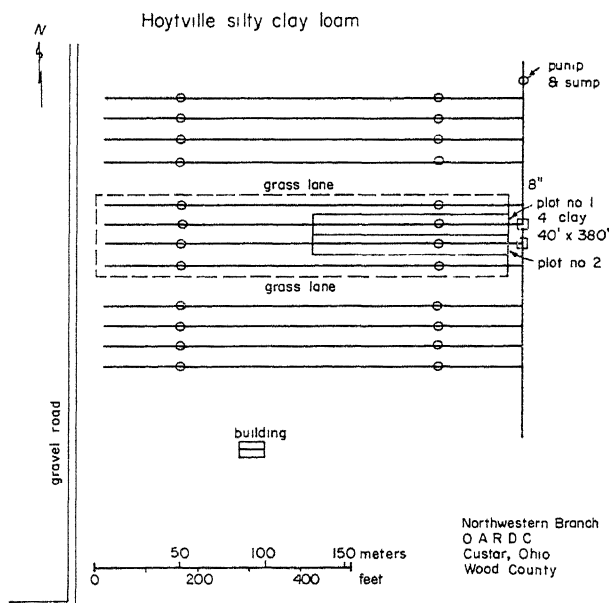


FIG. 6.—Hoytville soil site.

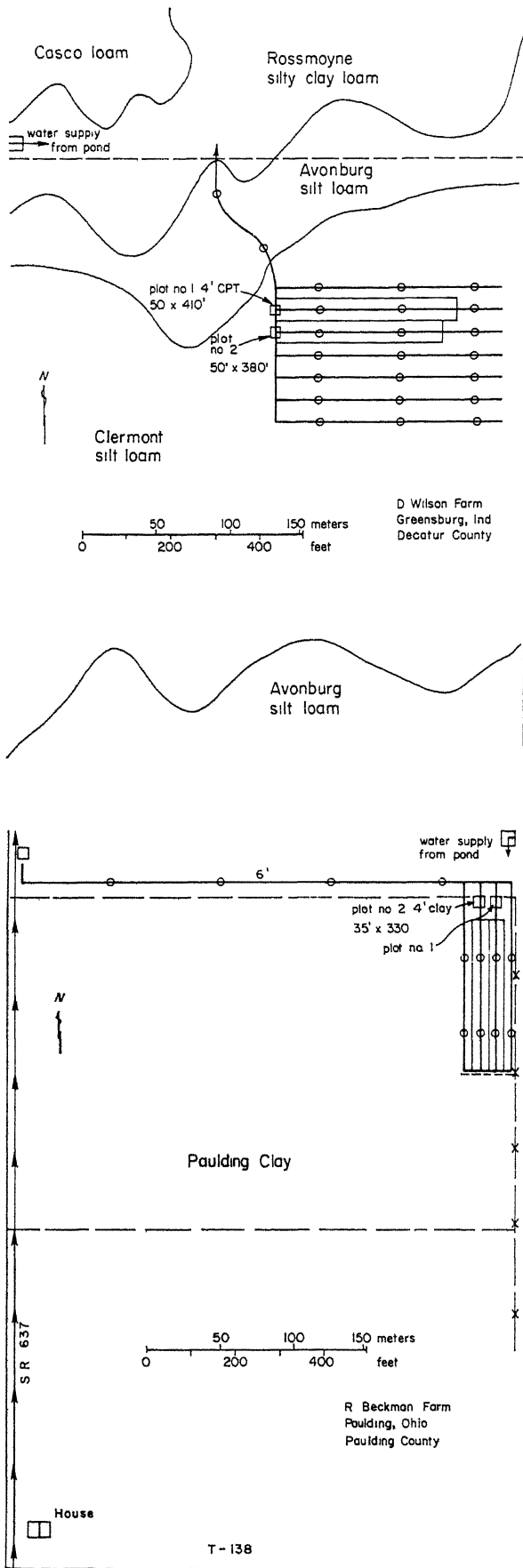


FIG. 7.—Clermont (Indiana) soil site.

Clermont Silt Loam (Indiana) (Typic Ochraqualf)

Pipe drains were installed in 1968. Old hay was placed in the backfill of the trench during construction. The field (Fig. 7) was in corn each of the last 4 years (1975-1978) and in soybeans in 1974. The field was fall plowed in 2 out of the last 4 years prior to 1978, followed each spring by disking several times as needed before planting. Prior to testing in 1978, the field had been chisel-plowed and disked; however, the surface remained in a fairly rough condition.

Paulding Clay (2) (Typic Haplaquept)

This field (Fig. 8) was cleared of trees in 1967 and pipe drains were installed in 1969. Soybeans were grown in 1978, corn in 1977, and wheat in 1976. Normal tillage operations included fall plowing, with the use of a field cultivator and spiked harrow in the

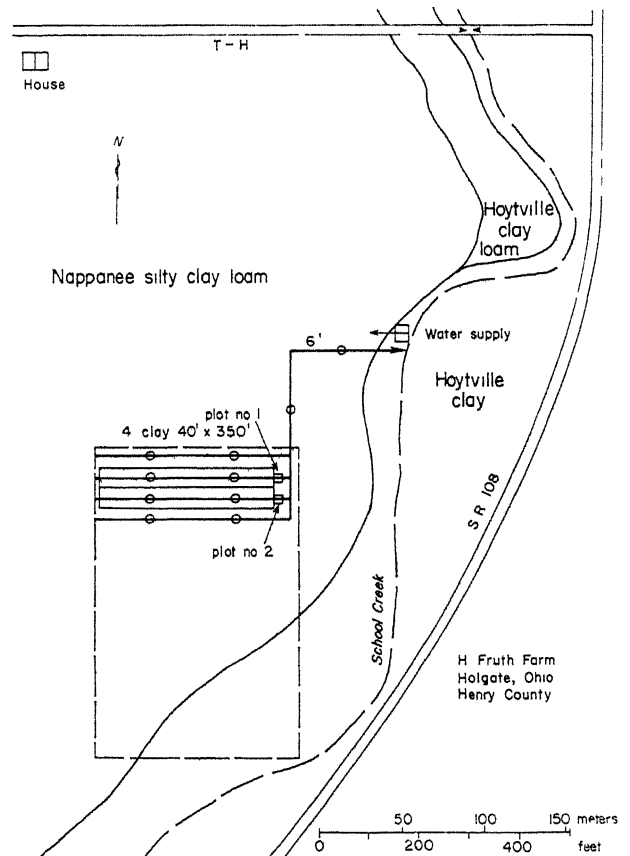


FIG. 9.—Nappanee soil site.

FIG. 8.—Paulding (2) soil site.

TABLE 3.—Average Measured Drainable Porosities by Soil Series.

Soil Type	Plot No.	Test No.	Drainable Porosities by Depth Increments		
			0-10 cm	0-20 cm	0-30 cm
Toledo, deep	1C	1	0.036	0.054	0.053*
	1C	2	0.104	0.060	0.069*
	1C	3	0.122		
	1C	4	0.062	0.066	0.052
	3C	1		0.051	0.034
	3C	2	0.057	0.048	0.048*
	3C	3	0.121	0.075	
	3C	4	0.072	0.059	0.055
Average			0.082	0.059	0.052
Toledo, shallow	1	1	0.078	0.045	
	1	2	0.141	0.061	0.043
	2	1	0.155	0.097	
	2	2	0.035	0.036	0.032
	4	1	0.071		
	4	2	0.075	0.046	0.036*
Average			0.093	0.057	0.037
Roselms	1	1	0.062	0.068	0.060*
	1	2	0.070	0.050	
	2	1	0.058	0.081	
	2	2	0.055	0.074	
Average			0.061	0.068	0.060
Paulding (1)	1	1	0.101		
	1	2	0.131		
	2	1	0.034		
	2	2	0.068		
Average			0.084		
Latty	1	1	0.082	0.054	0.038*
	1	2	0.099	0.051	0.036
	2	1	0.106	0.075	0.063
	2	2	RAIN		
Average			0.096	0.060	0.046
Clermont (Ohio)	1	1	0.099	0.067	0.055
	2	1	0.133	0.076	0.057
	1	2	RAIN		
	2	2	RAIN		
Average			0.116	0.072	0.056
Avonburg	1	1	0.051	0.041	0.036*
	1	2	0.071	0.046	0.038
	2	1	0.078	0.055	0.047
	2	2	0.075	0.049	0.040
Average			0.069	0.048	0.040
Hoytville	1	1	0.053	0.047	0.039
	1	2	0.066	0.048	0.045
	2	1	0.076	0.068	0.054
	2	2	0.073	0.064	0.052
Average			0.067	0.057	0.047
Clermont (Indiana)	1	1	0.075	0.058	0.048
	1	2	0.042	0.039	0.039
	2	1	0.050	0.049	0.044
	2	2	0.077	0.057	0.049
Average			0.061	0.051	0.045
Paulding (2)	1	1	0.082	0.071	0.067
	1	2	0.125	0.086	0.089
	2	1	0.096	0.082	0.069
	2	2	0.108	0.064	0.065
Average			0.103	0.076	0.073
Nappanee	1	1	0.072	0.070	0.054
	1	2	0.079	0.065	
	2	1	0.069	0.067	0.055
	2	2	0.096	0.069	
Average			0.079	0.068	0.054

*Actual water table depth slightly less than 30 cm.

TABLE 4.—Average Measured Drainage Coefficients by Soil Series.

Soil Type	Drainage Coefficient by Depth Increments*					
	0-10 cm		0-20 cm		0-30 cm	
	mm/d	in/d	mm/d	in/d	mm/d	in/d
Toledo, deep	8	0.32	12	0.46	16	0.61
Toledo, shallow	9	0.37	11	0.45	11	0.44
Roselms	6	0.24	14	0.54	18	0.71
Paulding (1)	8	0.33				
Latty	10	0.38	12	0.47	14	0.54
Clermont (Ohio)	12	0.46	14	0.57	17	0.66
Avonburg	7	0.27	10	0.38	12	0.47
Hoytville	7	0.26	11	0.45	14	0.56
Clermont (Indiana)	6	0.24	10	0.40	14	0.53
Paulding (2)	10	0.40	15	0.60	22	0.86
Nappanee	8	0.31	14	0.53	16	0.64

*Drainage coefficient = water table depth X average porosity (Table 3). This depth is the flow during drawdown to the drained depth indicated following shut-off of sprinkling.

spring. The field was in soybean stubble and very flat at the time of testing.

Nappanee Silty Clay Loam (Aeric Ochraqualf)

Pipe drains were installed in 1976 (Fig. 9). Recent crop history included corn 1977, soybeans 1978, and a growing wheat crop with clover seedlings at the time of testing in 1979.

DRAINABLE POROSITY

The average measured drainable porosities by soil series for three water table depths from the surface are shown in Table 3. The highest values were in the top 10 and 20 cm depths as these depths are within the plow layer. The porosities to 10 cm depth would tend to be high due to flow contributions by downward seepage from isolated spots of surface water and to be decreased by low *initial* water tables. The relationship between initial water tables and porosity at 10 cm depth was inconsistent. Evaporation losses from the water table were computed by multiplying pan evaporation by 0.7 for the 10 cm depth, 0.6 for the 20 cm depth, and 0.5 for the 30 cm depth. The average porosities for each soil were taken to compute the spacings for that soil for their respective drawdown depths.

Using the average drainable porosities in Table 3 for each soil, the drainage coefficients were computed as shown in Table 4. The measured coefficients for 0 to 10 cm depths are about 13% less than the present recommendation of 9.5 mm/d ($\frac{3}{8}$ in/d). For the 0 to 20 cm drawdown depth, the average drainage coefficient increased to about 12.7 mm/d (0.5 in/d), 34% more than present recommendations. The 20-cm depth is a practical drawdown depth for most field crops. However, it may not be necessary to design for more than 9.5 mm/d as the return period for rainfall equal to the irrigation depth is about once in 4 years. Studies by Hoover and Schwab (3) on Nappanee silt loam near Tiffin, Ohio, showed that the 9.5 mm/d coefficient would occur on the average only 0.7 day each year. The Roselms and Paulding soils usually had higher drainable porosities at 20 cm depth than at 10 cm. Such results are not consistent with the other soils. The data in Table 4 by them-

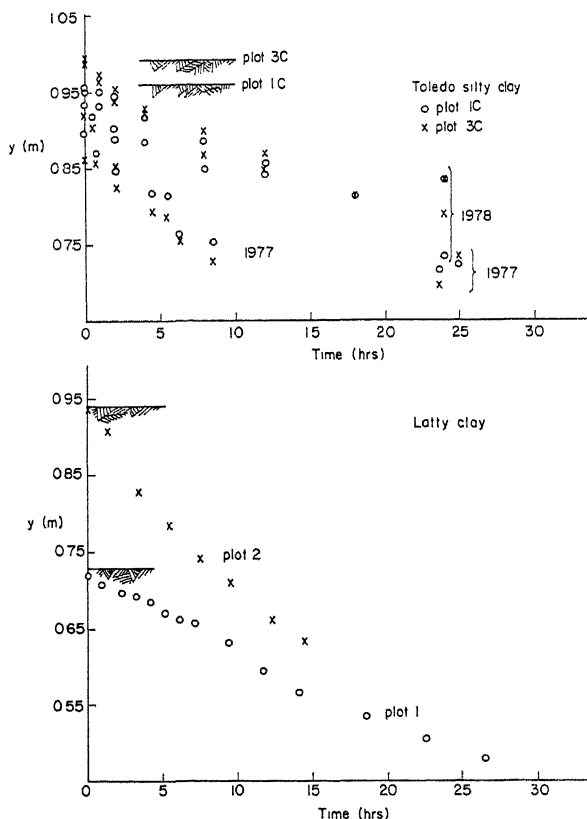


FIG. 10.—Water table drawdown at midspacing for Toledo and Latty soils.

selves do not justify changing the percent design drainage coefficient.

Average water table drawdowns at the midspacing for four selected soil types are shown in Figures 10, 11, and 12. These depths were not corrected for evapotranspiration as was done when computing drainable porosities. The drawdowns for the other soils (drawdowns not shown) were similar to the ones shown.

The variability between the two plots for the Latty soil and between test runs in 1977 and 1978 for the Toledo soil are shown in Fig. 10. Since the tests were run as uniformly as possible, the differences are due to drain depth, the soil hydraulic conductivity, or inherent characteristics due to time. In the Toledo tests, corrections were not made for temperature, but these are believed to be small. Additional comparisons for tests made in 1963 on the Toledo soil will be discussed later. For the Latty soil the rate of drop of the water table is much greater for the deep tile than for the shallow tile. Similar results were obtained for the Toledo soil.

The water table levels for the Clermont soil sites in Ohio and Indiana are shown in Fig. 11. For the first 10 to 15 hours the levels dropped faster at the Ohio site, but after that time they were slower than at the Indiana site. In contrast to the Clermont soil, the two Paulding sites were drastically different as shown in Fig. 12. At site (2) the farmer was careful not to till the soil when wet; otherwise the two sites have been cropped much the same. The preceding crop was soybeans at site (2) and meadow at site (1). Other than variation in soil properties, the reasons for such a wide difference in drawdown are not known.

TILE SPACING

Field effective values of K/f were computed for each water table pipe at (X/L) locations $1/10$, $1/4$, and $1/2$ the drain spacing. Average values are given in Table 5 for only the 20-cm water table depth. Consistently, the K/f values decreased as the water table measurements were taken closer to the drain. The major reason appears to be that for the pipe closer to the drain, the water table dropped more slowly than in an homogeneous soil, for which the theoretical curves were developed. This slower rate of drop is probably due to soil stratification. The low permeability of the subsoil causes the water to flow more horizontally near the surface rather than downward to the drains. Such flow would cause high water tables near the drain.

The average computed drain spacings by soil series for three rates of water table drawdown are shown in Table 6. For most field crops the 20-cm

depth should be adequate. These spacings are reasonably close to present recommendations. The Paulding (1) and the Toledo (shallow) soil spacings

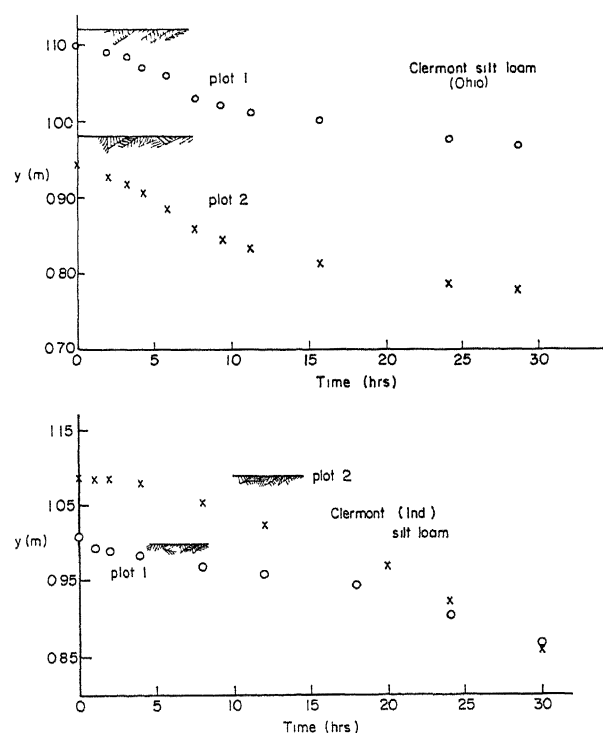


FIG. 11.—Water table drawdown at midspacing for Clermont (Ohio) and Clermont (Indiana) soils.

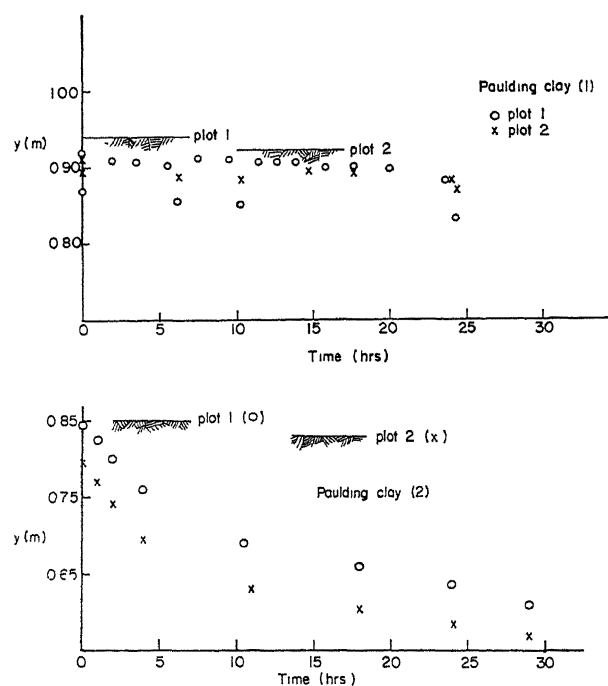


FIG. 12.—Water table drawdown at midspacing for two Paulding soil sites.

TABLE 5.—Field Effective K/f at 20-cm Water Table Depth.

Soil Type	Plot No.	Test No.	K/f		
			X/L = 1/2 m/h	X/L = 1/4 m/h	X/L = 1/10 m/h
Toledo, deep	1C	1	1.251	0.583	0.124
	1C	2	1.430	0.796	0.116
	1C	4	0.362	0.215	0.045
	3C	1	1.503	0.767	0.186
	3C	2	1.727	0.899	0.195
	3C	4	0.343	0.138	
Average			1.103	0.566	0.133
Toledo, shallow	1	1	0.133	0.073	0.022
	1	2	0.340	0.248	0.096
	2	2	0.491	0.424	0.618
	Average		0.321	0.248	0.245
Roselms	1	1	0.143	0.084	0.019
	2	1	0.152	0.077	0.014
	Average		0.148	0.080	0.017
Paulding (1)	All tests had midspacing water table depths less than 20 cm.				
Latty	1	1	1.148	0.597	0.439
	2	2	0.647	0.713	0.600
	Average		0.898	0.655	0.519
Clermont (Ohio)	1	1	0.210	0.100	0.035
	2	1	0.341	0.217	0.049
	Average		0.276	0.159	0.042
Avonburg	1	1	0.571	0.232	0.060
	1	2	0.597	0.235	0.077
	2	1	0.586	0.244	0.050
	2	2	0.769	0.241	0.059
	Average		0.631	0.238	0.061
Hoytville	1	1	1.417	0.684	0.282
	1	2	0.659	0.447	0.193
	2	1	1.138	1.064	0.355
	2	2	0.439	0.665	0.274
	Average		0.913	0.715	0.276
Clermont (Indiana)	1	1	0.379	0.501	0.535
	1	2	0.458	0.502	0.518
	2	1	0.409	0.571	0.339
	2	2	0.465	0.469	0.264
	Average		0.428	0.511	0.414
Paulding (2)	1	1	0.679	0.375	0.071
	1	2	0.476	0.243	0.041
	2	1	0.986	0.576	0.071
	2	2	0.627	0.362	0.048
	Average		0.692	0.389	0.058
Nappanee	1	1	0.878	0.468	0.078
	1	2	0.691	0.380	0.065
	2	1	0.812	0.385	0.066
	2	2	0.645	0.315	0.052
	Average		0.757	0.387	0.065

TABLE 6.—Computed Spacings for Pipe Drains by Soil Series.

Soil Type	Plot No.	Test No.	Depth in m	Spacing in Meters for Midplane Water Table Drop to Depth Shown in 1 Day		
				10 cm	20 cm	30 cm
Toledo, deep	1C	1		55.4*	19.0	
	1C	2		30.0	20.0	
	1C	3		17.3		
	1C	4		19.5	10.2	5.2
	3C	1			21.5	10.3
	3C	2		52.3*	22.8	
	3C	3		20.1		
	3C	4		20.7	10.3	5.0
	Average		0.97	21.5	17.3	6.8
Toledo, shallow	1	1		5.4	2.8	
	1	2		6.6	4.5	2.8
	2	1		5.0		
	2	2		8.7	5.5	
	4	1		10.5		
	4	2		13.6		
	Average		0.46	8.3	4.3	2.8
Roselms	1	1		15.9	7.3	
	1	2		14.6		
	2	1		37.8*	7.5	
	2	2		17.2		
Average			1.11	15.9	7.4	
Paulding (1)	1	1		5.3		
	1	2		5.5		
	2	1		5.0		
	2	2		†		
	Average		0.93	5.3		
Latty	1	1		19.2	13.7	
	1	2		†		
	Average		0.73	19.2	13.7	
	2	1		30.9*	20.4*	15.5*
	2	2		16.0	13.6	12.7
	Average		0.94	16.0	13.6	12.7
	Average (both depths)		0.84	17.6	13.7	12.7
Clermont (Ohio)	1	1		19.2	8.9	5.3
	1	2		†		
	2	1		23.5	9.9	5.8
	2	2		†		
	Average		1.05	21.3	9.4	5.6
Avonburg	1	1		20.2	12.8	8.5
	1	2		24.0	13.1	8.4
	2	1		25.5	12.7	
	2	2		27.9	14.6	8.4
	Average		0.96	24.4	13.3	8.4
Hoytville	1	1		41.9	22.5	13.9
	1	2		26.7	15.4	10.6
	2	1		43.4	20.7	12.9
	2	2		21.8	12.8	9.9
	Average		1.05	33.5	17.9	11.8
Clermont (Indiana)	1	1		12.7	11.0	8.4
	1	2		16.0	12.0	†
	2	1		18.6	12.2	9.5
	2	2		14.9	13.0	10.5
	Average		1.04	15.6	12.1	9.5
Paulding (2)	1	1		28.9	12.4	7.0
	1	2		21.5	10.4	4.0
	2	1		33.4	14.3	7.3
	2	2		27.7	11.4	4.6
	Average		0.84	27.9	12.1	5.7
Nappanee	1	1		40.2	14.1	7.6
	1	2		34.3	12.5	†
	2	1		41.8	14.3	7.7
	2	2		31.5	12.7	†
	Average		0.89	37.0	13.4	7.7

*Not included in average due to low initial water table depth.

†No calculations performed due to rainfall.

‡Water table did not reach this depth.

TABLE 7.—Variability of Drain Spacings for Toledo Soils, 1977-78 Tests.

	Plot No.	Test No.	Spacings in Meters for Midspacing Water Table Drop to Depth Shown in 1 Day		
			10 cm	20 cm	30 cm
Toledo, deep	1C	1	(55.4)*	19.0	
		2	30.0	20.0	
		3	17.3		
		4	19.5	10.2	5.2
Average	1C		22.3	16.4	5.2
		3C		21.5	10.3
				22.8	
				20.1	
Average	3C	1		21.5	10.3
		2	(52.3)	22.8	
		3	20.1		
		4	20.7	10.3	5.0
Overall average			21.5	17.3	6.8
Standard deviation, s			4.8	5.6	3.0
Coefficient of variation, %			22.4	32.4	44.0

*Values in parentheses not included in the averages.

are quite narrow. Depths shown are actual depths for the systems tested. Recommended depths could likely be varied at least 10% for the same spacings.

Although the deep and shallow Toledo sites were about 300 m apart, the shallow site had a much lower K/f and thus a lower spacing. The shallow depth also contributed to the narrower spacing. The deeper depth is recommended for this soil.

The variability of drain spacings for Toledo soil (deep depth) is shown in Table 7. More tests were conducted on Toledo than any other soil. By omitting the one high spacing in 1C and 3C plots at 10 cm drawdown, the variation among individual tests was 22.4%. For unknown reasons the percentage variation was higher for spacings computed at 20 and 30 cm drawdown. Tests 1 and 2 were made in June 1977 and tests 3 and 4 in June 1978, but the crop and other conditions were similar.

Spacings from similar tests in 1963 were compared to those taken in 1977 and 1978 for the Toledo soil (Table 8). In 1963 the crop was corn and the same plots were irrigated in June, but drainable po-

rosity was not corrected for evaporation and spacings were calculated using the van Schilfgaarde spacing equation (14). Four plot replications were averaged in 1963 rather than only two in 1977-78. Considering these differences, the computed spacings were within 19% for the 20 cm water table depth as shown in Table 8. These differences from spacings computed in 1963 were less than those between the 1977 and 1978 results.

DISCUSSION

Water table measurements in some tests were erratic due in part to air entrapment and to a lag of water flow into and out of the measuring wells. For the initial starting drawdown time, the average water table was several centimeters below the soil surface in some tests. With low initial water tables, drain spacings tended to be large, especially for the 0 to 10 cm drawdown. In other tests the effect appeared to be minimal or inconsistent. In some cases the water table would rise after the initial time, indicating filling of the test well from surface water or a lag in inflow.

Pan evaporation factors were varied from 0.7 to 0.5. The rationale for the varying coefficients is that evaporation would have less effect with an increase in water table depth. Since most tests were run in late fall and early spring, pan evaporation was low, minimizing the effect of evaporation.

Considering or neglecting evapotranspiration (ET) during drawdown affects the computed drainable porosity. When ET is added to the outflow, porosity is increased, K/f is decreased, and the resulting drain spacing is decreased as the one-half power of K/f, theoretically. Comparison of drain spacings

TABLE 8.—Comparison of 1963 and 1978 Computed Spacings for Toledo Soil, Deep Drains.

Date of Tests	Spacings in Meters for Midspacing Water Table Drop to Depth Shown in 1 Day		
	10 cm	20 cm	30 cm
June 1977 and 1978	21.5	17.3	6.8
June 1963*	21.3	14.0	9.8
Percent Difference	—0.8	—19.1	44.1
(1977-78 values less 1963 values)			

*Data from Hoffman and Schwab (2).

using K/f based on zero evapotranspiration and those based on measured pan evaporation is shown in Table 9. Clermont (Ohio) soil tests were selected because the differences in ET were higher than for the other soils. With ET assumed as 0.7 of pan evaporation, drain spacings for the 20-cm drawdown depth were 16.1% less than when ET was zero. For this reason measured ET was considered in computing K/f values for all soils. Further research is needed to delineate more specifically the relationship of pan evaporation and loss of water from the water table.

Paulding (2) site data showed much higher drawdown rates than Paulding (1). For the 0 to 10 cm drawdown rates, the drain spacings were 5.3 and 27.9 m for Paulding (1) and (2) sites, respectively. At the Paulding (1) site the water table reached the 20-cm depth during only one of the four tests, so a comparison at this depth was not made. The two sites were only about 5 miles apart. The farmer at site (2) was conscientious about not working the soil when wet. Other soil management practices included a corn, soybean, and wheat crop rotation and the use of smaller equipment than most other farmers in the area to reduce soil compaction. Such widely different spacings as mentioned above should raise serious questions about using soil type as the only basis for drain spacing.

Some characteristics unique to the Clermont (Indiana) site are of interest. Although the soil surface was in a rough condition at the beginning of the tests, repeated rains and irrigations resulted in some surface sealing. This sealing together with the gentle slope at the site resulted in more surface runoff than was experienced at the other sites. These studies showed that surface drainage along with tile drainage is important for this soil.

The Nappanee site had good natural surface drainage which prevented much ponded water. This condition accounted for the low initial water table compared to other sites.

For the last four soils in Table 6, hydraulic conductivities were corrected to a standard temperature of 10° C (50° F). Although the effect of temperature on drain spacing is likely to be small, such a correction does remove this variable when comparing spacings for the various soils. When soil temperatures are higher than 10° C (50° F), spacings given in this report could be increased slightly.

The depth from the drain to the impermeable layer was assumed to be zero for all computations. Increasing the depth of the impermeable layer in one soil from zero to $d/h_0 = 0.5$ gave less than a 5% difference in drain spacing. Skaggs (9) found a similar effect. He indicated that this factor tends to cancel out when the K/f obtained from drawdown is used to

TABLE 9.—Comparison of Drain Spacings Calculated with Zero and Measured ET for Clermont (Ohio) Soils.*

	Midplane Water Table Depth		
	10 cm	20 cm	30 cm
Spacing in meters ET = 0	22.2	11.2	8.3
Spacing in meters ET, mm/hr (0.7 pan evaporation)	21.3 (0.34)	9.4 (0.20)	5.6 (0.18)
Percent Difference in Spacing with ET	4.1	16.1	32.5

*For test 1 only.

predict drain spacings.

The greatest opportunity for improving drain spacing recommendations by the procedure outlined here is to improve the accuracy of water table measurements. Two possible ways are to increase the number of pipes, especially at the midspacing locations, and to develop a more responsive sensor. Three pipes at each midspacing were installed during tests on the last four soils in Table 6.

SUMMARY

Hydraulic conductivity (K) and drainable porosity (f) were evaluated for eight slowly permeable soil types by saturating the soil to the surface at each field site by sprinkler irrigation. Water table measurements were taken at three distances from parallel drains and corrections were made for evaporation to compute drainable porosity and K/f .

For the existing boundary conditions, K/f values were determined for each soil according to procedures developed by Skaggs (9). From these K/f values, drain spacings were computed for drawdown rates from the soil surface of 10, 20, and 30 cm/day. For the 20 cm/day rate, drain spacing for Toledo silty clay was 17 m (57 ft); Roselms clay loam 7 m (24 ft); Latty clay 14 m (45 ft); Clermont (Ohio) silt loam 9 m (31 ft); Avonburg silt loam 13 m (44 ft); Hoytville silty clay loam 18 m (59 ft); Clermont (Indiana) silt loam 12 m (40 ft); Paulding (2) clay 12 m (40 ft); and Nappanee silty clay loam 13 m (44 ft). The depth of these drains was about 0.8 to 1.0 m (2.6 to 3.3 ft). For another Toledo site having a drain depth of 0.5 m (1.5 ft), the spacing was 4 m (14 ft). In the Paulding (1) clay soil the water table did not drop to 20 cm depth even after 5 days. For eight test runs on Toledo soil in 1977 and 1978, the coefficient of variation of the computed spacings was 32.4% at the 20 cm/day rate. Compared to tests in 1963 on the same plots, but using another spacing equation, the spacings were about 19% more than the 1963 values.

Evapotranspiration had an important effect on K/f and spacing. For Clermont (Ohio) soil at the 20 cm/day rate of drawdown, spacings were 16.1% less when evapotranspiration (ET) was considered compared to assuming zero ET. Depth from drain to the impermeable layer was taken as zero, but it was found to have a small effect on spacing. Water table levels were not always consistent and more precise measurement techniques need to be developed.

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APPENDIX A

EQUIPMENT AND INSTRUMENTATION

The following equipment was required in the field:

Quantity	Description
1	ITT Marlow Model 4D85 portable centrifugal pump, 200 gpm at 230 ft head
36	30' x 4" diameter aluminum irrigation pipe
30	30' x 2" diameter aluminum irrigation pipe
36	3' x 1" diameter aluminum risers with 1/8" nozzles and full circle heads
	assorted couplings, tees, reducers, elbows and end plugs
1	30' pipe trailer, 2-wheel
1	3/4 ton pickup with winch and tool boxes
1	backhoe (rented)
1	Little Beaver Earth Drill, snap on 3 1/2' x 1 1/2" dia. auger
100	5' x 1/2" dia. steel conduit perforated at 4" intervals and wrapped with muslin
2	3' x 4' x 6' plywood boxes for weir and pump
2	sump pumps with automatic on/off, Little Giant Model 6CIA
1	1500-watt McCullough generator with 4 hp Briggs & Stratton engine
2	low pressure two-direction valves with 4" fittings
2	30° V-notch weirs
2	water level recorders, Friez Model FW-1
1	weather shelter
1	hygrothermograph
1	recording rain gage
1	nonrecording rain gage
1	thermometer
1	anemometer, Science Associates Model 403
1	U. S. Weather Bureau Class A evaporation pan, hook gage and wooden pallet
1	4" diameter totalizing flow meter, Sparling Model S/N 108535
	assorted tools
6	3' x 1" diameter aluminum risers with 9/64" nozzles and part circle heads
1	4' x 1/4" diameter plastic blowtube graduated in centimeters

APPENDIX B

GLOSSARY OF SYMBOLS

- d depth of impermeable barrier below drain flow line (m)
- D d/h_0 (dimensionless)
- Dd average drawdown (cm)
- e pan evaporation plus deep percolation (m/h)
- ET evapotranspiration from water table (m/h)
- f drainable porosity (dimensionless)
- h depth of impermeable barrier below water table (m)
- h_0 depth of impermeable barrier below initial water table (m)
- H.I. height of survey instrument (elevation) (ft)
- K hydraulic conductivity (m/h)
- L drain spacing (m)
- q drain flow (mm/h)
- t time (h or min)
- t_0 time of initial water table (h or min)
- X horizontal distance from drain centerline (m)
- y depth of drain flow line below water table (m)
- y_0 depth of drain flow line below initial water table (m)
- τ (tau) intermediate value to compute K/f (dimensionless)
- μ (mu) intermediate value to compute evapotranspiration or deep percolation (dimensionless)

GLOSSARY OF COMPUTER VARIABLES

A. Survey Variables

1. GROUND—ground reading of observation wells
2. TOP—reading at top of observation wells
3. PROBE—reading at top of probe touching tile line (ft)
4. CROSS—cross-section letter
5. LPROBE—length of probe touching tile line (ft)
6. TILDIA—tile diameter (ft)
7. HI—height of instrument, elevation (ft)
8. ELEVAT—ground elevation of observation wells (ft)
9. FLOLIN—negative distance from instrument height to flow in tile line (ft)
10. TILSPC—distance between tile lines for each cross-section (ft)
11. PIPE—distance from top of observation well to flow in tile line (ft)
12. X—location of observation wells with respect to tile line (ft)
13. OLDCRS, NEWCRS, CROSS—data check for change in cross-section and determining total observations per cross-section

B. Field Test Variables

1. HOURS, MINS—time of observation
2. TSTART—time at beginning of test (hrs)
3. TIME—elapsed time from beginning of test (hrs)
4. CTIME—time between readings (hrs)
5. DATE—month, day, year of observation
6. ET—average evapotranspiration rate (m/hr)
7. TE—total evapotranspiration from beginning of test (cm)
8. ES—amount of evapotranspiration between observations (cm)
9. RAIN—amount of rainfall between observations (cm)
10. TORAIN—total rainfall from beginning of test (cm)
11. TILFLO—amount of tile flow between observations (cm)
12. TOTILE—total tile flow from beginning of test (cm)
13. REDING—depth to water in observation well from top of pipe (cm)

C. Tile Spacing Program Variables

1. SMALLY — y
2. YZERO — y_0
3. BIGY — $Y = y/y_0$
4. HZERO — h_0
5. SMALLD — d
6. BIGD — $d/h_0 = D$
7. XOVERL — X/L
8. EL — L_1
9. F — f
10. DIST — L_2
11. KOVF — K/f
12. SUBTR — design drawdown
13. CURNTE — e
14. KAY — K
15. SMALY2 — (y/y_0) design

D. Porosity Program Variables

1. WGAVG—weighted average drawdown, total or incremental depending on subscript (cm)
2. DIFF—change in height of water table at each point, total or incremental depending on subscript (cm)
3. SUMDIF—changes in water table depth are summed for similar points, total or incremental depending on subscript (cm)
4. SMALLF—incremental porosity
5. TOTALF—overall porosity

APPENDIX C

COMPUTER OPERATIONS AND ASSUMPTIONS

A. Porosity Calculation (F-VALUE program)

$$f = \frac{Q-ET}{WGAVG} \quad (\text{STATEMENT 241, 242})$$

f = porosity

Q = tile flow

ET = water loss from pan (—), and rainfall (+). For 10 cm drawdown use ET = 0.7 pan, for 20 cm ET = 0.6 pan, and for 30 cm ET = 0.5 pan.

WGAVG = weighted grand average of drawdown
and

$$WGAVG = 0.35 Dd (X/L = 1/10), +0.40 Dd (X/L = 1/4), +0.25 Dd (X/L = 1/2) \quad (\text{STATEMENT 235})$$

Dd = average drawdown at various distances between tile lines

B. Tile Spacing Calculation (TILSPAC program)

1. GETTAU interpolation based on obtaining a K compatible with two equations:

$$K/f = \frac{\tau L^2}{h_0 t_1} \quad (1) \quad (\text{SUBROUTINE DSTNCE, STATEMENT 18})$$

where τ is selected from the chart for a proper μ :

$$\mu = \frac{e L^2}{K h_0^2} \quad (2) \quad (\text{SUBROUTINE DSTNCE, STATEMENT 22})$$

2. DIST (spacing) calculated by:

$$L_2 = \sqrt{\frac{K}{f} h_0 t_2 / \tau_2} \quad (\text{SUBROUTINE DSTNCE, STATEMENT 35})$$

C. Inaccurate Data Treatment

1. All readings are limited to the soil surface. If a reading is read above the surface, it is set equal to a reading on the soil surface.
2. A test will be terminated when rainfall ($ET > 0$) is accompanied by a rise in the water table levels at any of the test wells.
3. Any zero readings or dry wells (9999) are flagged by a —999, and are ignored in the calculation.
4. Program must have three cross-sections per test. False cross-sections must be supplied when there are only one or two valid cross-sections. A false deck should be blank with a cross-section character where necessary. False observation well data require only one card per cross-section.
5. If a zero appears as the initial reading for a given well, an extrapolation is attempted. Extrapolation depends on:
 - a. Number of consecutive zero readings. If greater than two, data for the given well are invalid.
 - b. Water table movement: if depth does not increase from second to third, first reading is set equal to second. If depth does increase, first reading is determined by a time based extrapolation using the second and third readings.
 - c. If the value of the third reading is nonzero and the second reading zero, the second reading is calculated based on the third and fourth reading. Then the first reading is calculated based on the second and third reading as before.

Extrapolation statements:

$$DEL = REDING(I, J, K+1) - REDING(I, J, K)$$

$$CTIME(I, K) = TIME(K, K) - TIME(I, K-1)$$

$$REDING(I, J, K-1) = REDING(I, J, K) - DEL * \frac{CTIME(I, K)}{CTIME(I, K+1)}$$

where K = 2 or 3 only.

(Refer to SUBROUTINE FIXUP of both programs)

APPENDIX D

SOIL CHARACTERISTICS BY SOIL SERIES

Soil	Depth cm	Horizon	Total Clay ≤ 0.002 mm	Total Silt 0.002mm to 0.05mm	Total Sand 0.05mm to 2.0mm	Bulk Density gm/cm ³	Water Content % (15 BAR) by weight	pH	Atterberg	
									LL	PI
									%	≤ 0.4mm
Avonburg	10	Ap	18.4	72.3	9.3	1.54	8.4	6.3	34	12
	100	11Bx2g	36.4	50.9	12.7	1.83	15.8	4.9	46	27
Clermont (Ohio)	10	Ap	22.0	68.4	9.6	1.69	9.4	6.6	34	13
	100	11B24tg	42.3	45.9	11.8	1.89	18.6	4.9	49	23
Clermont (Indiana)	10	Ap	12.4	72.2	15.4	1.63	5.7	6.4	27	6
	100	Bx1	20.3	55.5	24.2	1.77	9.8	5.0	30	12
Hoytville*	10	Ap	37.6	41.8	20.6	1.29	16.7	6.9	35	12
	100	B31	45.8	37.0	17.2	1.60	15.9	7.6	42	16
Latty	10	Ap	40.2	44.5	15.3	1.62	17.3	6.4	51	22
	100	B24g	35.3	49.4	15.3	1.80	15.4	7.9	42	21
Paulding (1)	10	Ap	56.5	24.4	19.1	1.59	23.5	6.1	51	21
	100	B32	57.9	20.7	24.4	1.86	18.5	7.8	52	25
Roselms	10	Ap	52.5	28.9	18.6	1.65	19.7	5.9	49	23
	100	B32	64.4	29.2	6.4	1.68	20.6	7.7	54	27
Toledo†	10	Ap	51.0	46.0	3.0	1.22	17.2	5.8	61	25
	100	C11	47.0	48.0	5.0	1.49	18.8	7.2	58	30
Nappanee	10	Ap	33.2	39.8	27.0	1.60	12.2	7.3	39	14
	100	C1	33.1	43.4	23.5	1.93	12.1	8.1	32	14

*Data obtained from Taylor, et al. (11), except for water content, pH, and Atterberg limits which are from Blevins and Wilding (1).

†Data obtained from OSU analyses, except for bulk density and water content which are from Schwab, et al. (8).

NOTE: All other soil analyses were performed by the U. S. National Soil Survey Laboratory, Lincoln, Neb., following procedures described in U. S. Soil Conservation Service (12). Bulk densities are for soil clods, except for Hoytville and Toledo soils. Data were not obtained for the Paulding (2) soil.

BETTER LIVING IS THE PRODUCT

of research at the Ohio Agricultural Research and Development Center. All Ohioans benefit from this product.

Ohio's farm families benefit from the results of agricultural research translated into increased earnings and improved living conditions. So do the families of the thousands of workers employed in the firms making up the state's agribusiness complex.

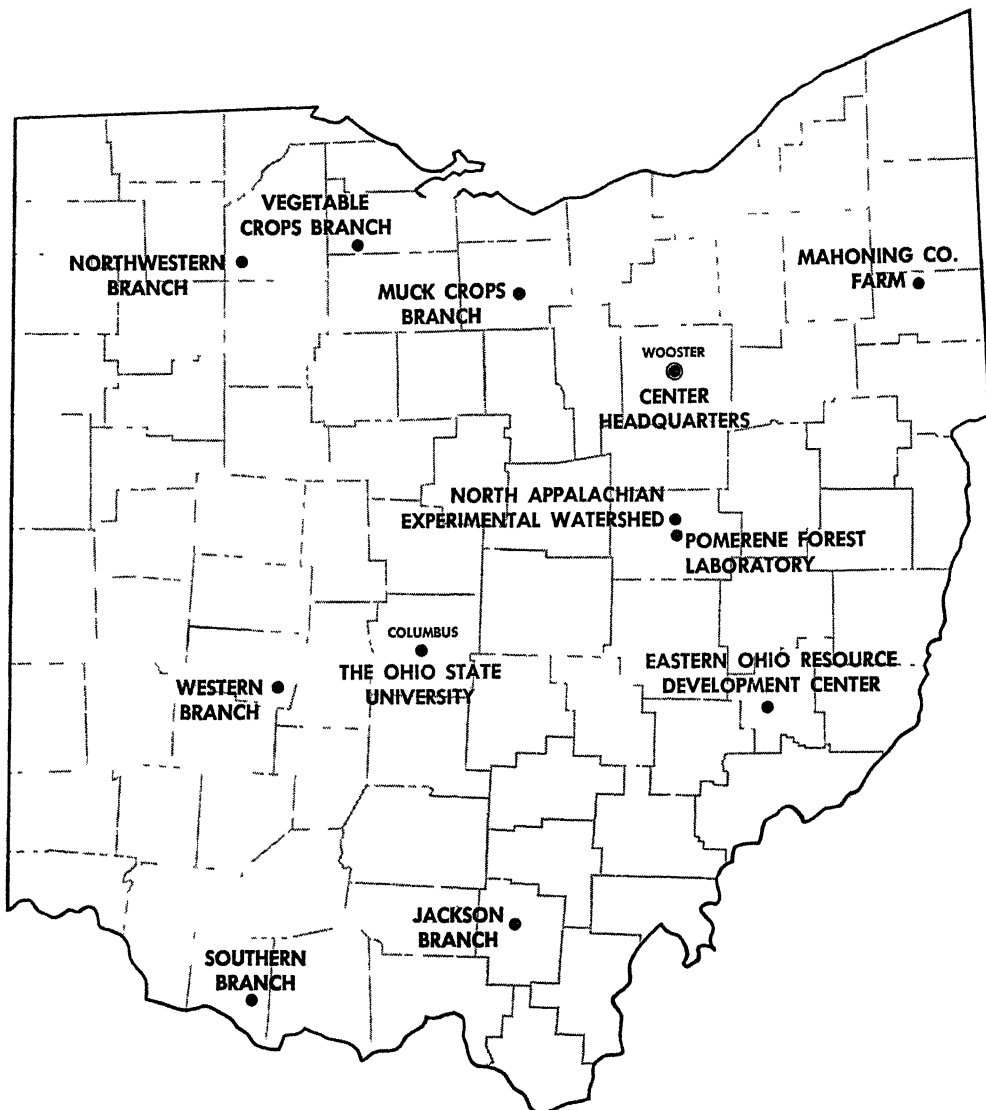
But the greatest benefits of agricultural research flow to the millions of Ohio consumers. They enjoy the end products of agricultural science—the world's most wholesome and nutritious food, attractive lawns, beautiful ornamental plants, and hundreds of consumer products containing ingredients originating on the farm, in the greenhouse and nursery, or in the forest.

The Ohio Agricultural Experiment Station, as the Center was called for 83 years, was established at The Ohio State University, Columbus, in 1882. Ten years later, the Station was moved to its present location in Wayne County. In 1965, the Ohio General Assembly passed legislation changing the name to Ohio Agricultural Research and Development Center—a name which more accurately reflects the nature and scope of the Center's research program today.

Research at OARDC deals with the improvement of all agricultural production and marketing practices. It is concerned with the development of an agricultural product from germination of a seed or development of an embryo through to the consumer's dinner table. It is directed at improved human nutrition, family and child development, home management, and all other aspects of family life. It is geared to enhancing and preserving the quality of our environment.

Individuals and groups are welcome to visit the OARDC, to enjoy the attractive buildings, grounds, and arboretum, and to observe first hand research aimed at the goal of Better Living for All Ohioans!

The State Is the Campus for Agricultural Research and Development



Ohio's major soil types and climatic conditions are represented at the Research Center's 12 locations.

Research is conducted by 15 departments on more than 7000 acres at Center headquarters in Wooster, eight branches, Pomerene Forest Laboratory, North Appalachian Experimental Watershed, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres

Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with Agricultural Research Service, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres